Acoustic Scattering in Deep Ocean Waveguides due to Small Scale Ocean Structure

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LONG-TERM GOAL

The long-term goal is to contribute to the understanding of long-range propagation of acoustic pulses in deep ocean environments. Emphasis is placed on broadband pulses centered at around 100 Hertz in oceans that have a well defined acoustic waveguide. This effort directly compliments the Long-range Ocean Acoustic Propagation Experiment (LOAPEX) that was performed in the fall of 2004.

OBJECTIVES

A primary objective is to test the hypothesis that an stochastic environmental model that includes internal waves and spice is adequate to explain the multiple forward scattering of acoustic pulses as they are propagated in range. The stochastic model is based on measurements of temperature, salinity, and pressure taken during LOAPEX.[1] Of primary consideration is to compare model results to LOAPEX data which used source of approximately 75 Hz, but extrapolation to other source frequencies (e.g. 250 Hz) is also an objective.

APPROACH

The approach taken is to attempt to first isolate the scattering problem to what is a large subset of the entire problem of transmitting acoustic pulses through the deep ocean waveguide. It can be established that in many deep ocean environments that are within the mid-latitudes, a large fraction of a pulse initiated from a point source does not interact with either the surface or the bottom. Constraining oneself to investigate this part of the acoustic pulse allows one to isolate the physics to that of weak, multiple forward scattering in the ocean volume. The refractive index in the ocean volume is known to change by less than about 5% in the vertical and about 100 times less than this in the horizontal. The range dependence in the ocean volume that gives rise to sound speed fluctuations is known to be concentrated in the upper ocean, near the thermocline and above. Oceanic disturbances such as meso-scale eddies, internal waves, spice, etc., all contribute to the range dependent sound speed fluctuations, and the constituent scales each of these oceanic phenomena are quite different. What has been demonstrated in the past through full wave modeling studies is that the smaller scale sound speed fluctuations play a more important role to predict the scattering process than the larger scale fluctuations, which are observed to be more relevant to the acoustic tomographic, where travel time sensitivity is concerned. With this in mind, this author concentrates on accurately modeling the

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14. ABSTRACT
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smaller scale fluctuations, taken to be internal waves and spice, and for the moment does not consider larger scale meso-scale eddies.

An additional feature exploited is in measuring the scattering in depth below lower turning point caustics, as opposed to above upper turning point caustics. To first order the sound speed in the North Pacific, where LOAPEX took place, exponentially grows above the depth where the minimum sound speed is attained (O(1km)) and linearly increases below this depth. This not only stretches out the diffractive region about the lower turning point depth compared to its complimentary upper turning point, it also facilitates a greater amount of depth scattering, as is observed in both modeling and data. Of possible greater benefit is the reduction of noise being generated near and above the mixed layer. This stretching effect as well as the reduced amount of noise allows one to possibly obtain greater precision in measuring the scattering into the 'forbidden region' about the turning points. It also directly relates to putting to rest questions regarding the 'shadow-zone' arrivals noted by Brian Dushaw from classified SOSUS data. [2]

WORK COMPLETED

With regards to the modeling of the internal waves and spice, the CTD profiles taken during LOAPEX were used to extract a spectral strength for high wavenumbers for density and sound speed, two state variables which were utilized to compute displacement spectra. Figure 1 illustrates how a state variable F gives rise to a displacement using the relationships

$$\zeta = \frac{F_{HP}}{(F'_{LP} - F'_{AD})}, \text{ and } \quad Strain \equiv \frac{d\zeta}{dz},$$

where the subscripts 'HP', 'LP', and 'AD' denote high pass filtered, low pass filtered, and adiabatic values, respectively. Using this methodology, developed through collaboration with Frank Henyey, periodograms were formed and then averaged locally in depth to yield spectra for internal waves and the total sound speed fluctuations. The total sound speed fluctuations are likely due to internal waves and spice. The assumption was made that spice follows a k^{-2} power law behavior, and this allowed progress to be made in modifying the internal wave model to include the effective contributions due to spice in a trivial manner. This researcher still has to complete some work on issues relating to how much the total sound speed fluctuation spectra is due to spice, and how much due to internal waves. It might turn out that some other oceanic process is giving rise to the rather large spectral levels (average GM=1.5) observed after the analysis was carried out. However, procedure was carried through and realizations of sound speed fields were generated, which were used for input to a full wave model based on the para-axial approximation to the Helmholtz wave equation.

Full wave modeling using the above prescription for the sound speed environment was carried out. Regions where comparisons to data were made at a particular station are shown in Figure 2. The data in these chosen regions were processed and the first order estimate of noise subtracted off to yield field intensity values at each of the 20 hydrophones in the lowest section of the LOAPEX deep vertical line array. Finally, integration of the region in time was performed on both the model and LOAPEX data to derive a measure of the scattering in depth below particular lower turning point caustics.

Other work completed includes a re-examination of the data. It was found that some of the calibrations of the raw LOAPEX data were not trustworthy, and some iterations with Rex Andrew and Linda Buck were done to finally insure the data was sufficiently correct to be used to further complete this study

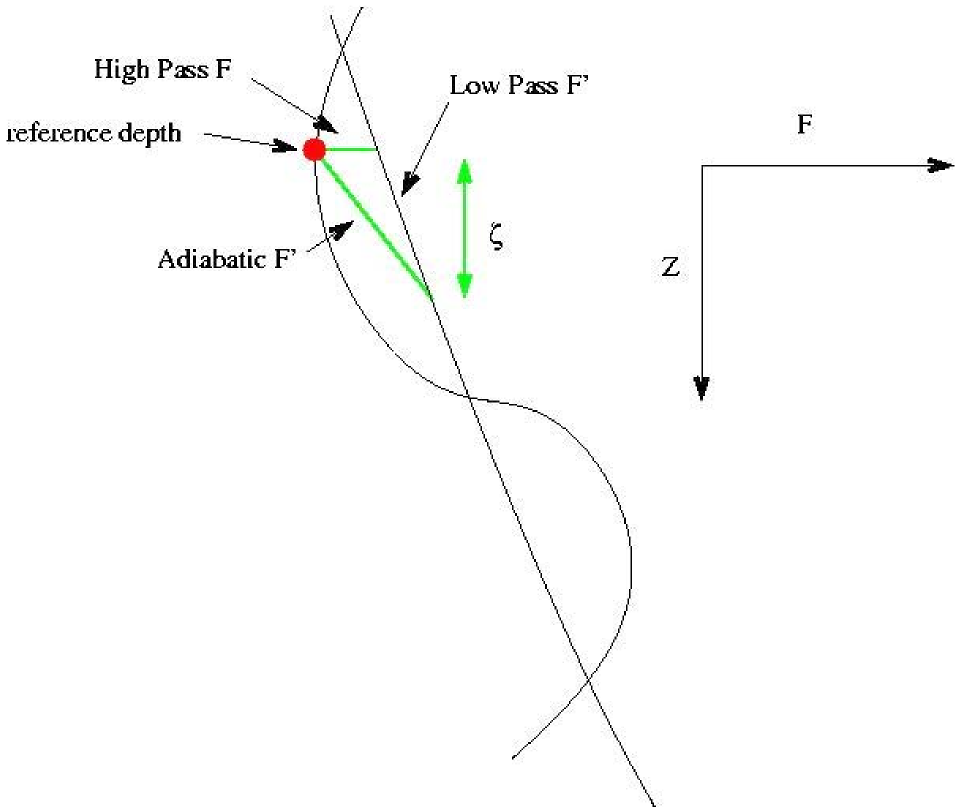

Figure 1. Heuristic diagram showing how a vertical displacement periodogram is constructed from a state variable F, which can be taken as either density or sound speed. The 's' shaped curve represents the value of the state variable as a function of depth z. The smooth curve represents a low pass filtering of the state variable data. The red dot indicating the reference depth shows that this method is local, necessitating that the CTD sample a high rate (< 10 spacing between samples).

and also include a comparison of absolute levels of acoustic intensity, as Peter Worcester et al. have done. It should be noted that the method used in this project of using time-integrated wavefield intensity provides a more precise measure than comparing absolute power levels, since the slope of the time-integrated intensity with depth is not sensitive to source power level or unknowns such as horizontal refraction. It seems logical to have model hypothesis testing procedures which have less unknowns to worry about.

Additionally, substantial modifications to the internal wave model were performed. This enabled the model to be more portable to different computer platforms, and also facilitates easier extension of the model to generate crossrange gradients of sound speed, which is desirable to compute travel time bias estimates due to internal wave-induced horizontal refraction, part of a collaborative work with Oleg Godine and Valery Zovorotny.

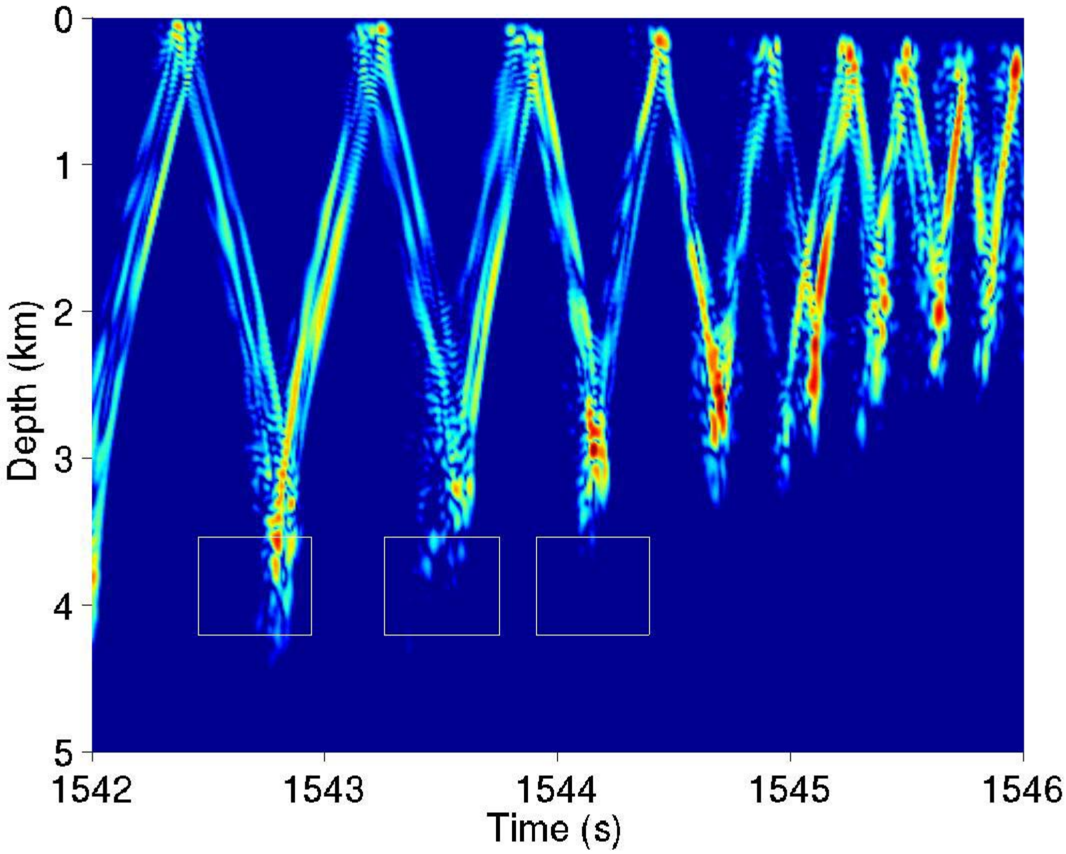

Figure 2. Wave field intensity produced by evolving a broadband point source (75 Hz center frequency, 37 Hz bandwidth) at a depth of 350 meters through a sound speed composed of a Lagrangian averaged background superposed with fluctuations due to spice (neutrally buoyant intrusions) and internal waves. Both the background and fluctuating sound speed were derived from CTD's taken during LOAPEX. The highlighted boxes show the regions where the time-integrations were performed, the upper and lower boundaries of the boxes are consistent with the depths of the 1st and 20th hydrophones of the lowest section of the deep vertical line array used during LOAPEX. The colors represent the sound intensity in dB without regard to an absolute level, with 35 dB dynamic range.

RESULTS

The highlight of our results thus far is shown in Figure 3. Here it is seen that the power law behavior of the scattering below the particular lower turning point caustic is in good agreement with the observations. This agreement was observed at other stations as well (T1000, and T1600). The scattering was insufficient at the shorter range stations to provide a meaningful comparison, and station T3200 has an inadequate signal to noise ratio to compare without modifying the processing technique.

The other primary result is that the LOAPEX data has been sufficiently tested for this researchers purposes, and now it is in a form that other researchers can utilize. A NASA summer student, Abigail McClintic, assisted this researcher in discovering problems with the LOPEX data processing, which both Rex Andrew and Linda Buck immediately ameliorated.

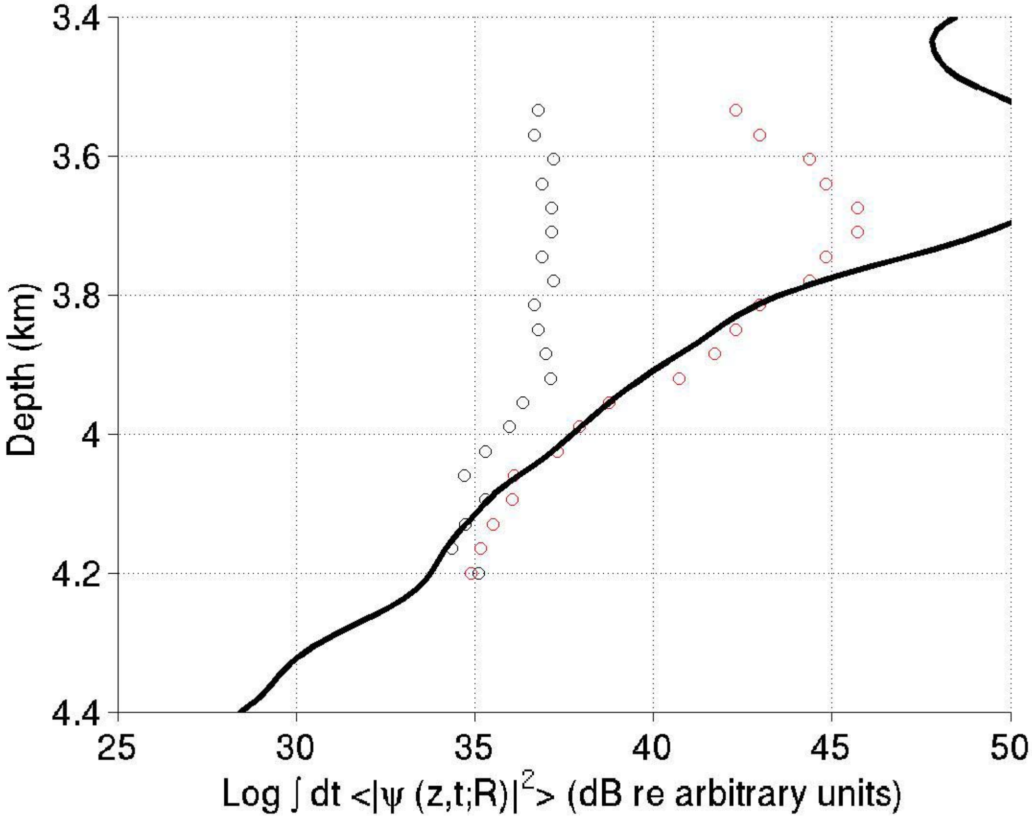

Figure 3. Time-integrated value of intensity for the boxes highlighted in Figure 2 (red circles—middle box, blue circles --- rightmost box). The modeled data is represented by the thick black curve for the middle box in Figure 2. Note there is no respect to absolute intensity levels, so it is the slope on a log scale, or functional shape that is the relevant comparison.

IMPACT/APPLICATIONS

This work is leading toward the development of an efficient numerical model for predicting the behavior of scalar wavefields as they evolve through random, weakly scattering waveguides.

RELATED PROJECTS

This work is related to the data analysis effort of LOAPEX. With respect to obtaining environmental data, this work is related to the effort of the SPICE project.

A student of Jim Mercer, Andrew White, has taken interest in being under this researchers supervision with regards to full wave modeling and the analysis of LOAPEX data. This student has been proceeding well, and it is anticipated that he will soon will have skills that will compliment the objectives of this project.

REFERENCES

[1] Mercer et al. "Cruise Report: Long-range Ocean Acoustic Propagation Experiment (LOAPEX)," APL-UW TR 0501, April 2005.

[2] Brian Dushaw, private communication.